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RESEARCH AND DEVELOPMENT TECHNICAL REPORT
CORADCOM- 77-0190-F

VEHICULAR INTERCOMMUNICATION SYSTEM

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February 1979

Final Report for Period 30 September 1977 - 31 October 1978

Prepared for:
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FORT MONMOUTH, NEW JERSEY 07703

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This is the final report for the design study of a vehicular intercommunication system primarily used in tracked vehicles. The report presents conclusions based on study efforts conducted from 30 September 1977 to 31 October 1978. A system which meets development specification, DS-AF-0246A(A), dated 14 February 1977, is discussed.

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See Addendum inside back cover

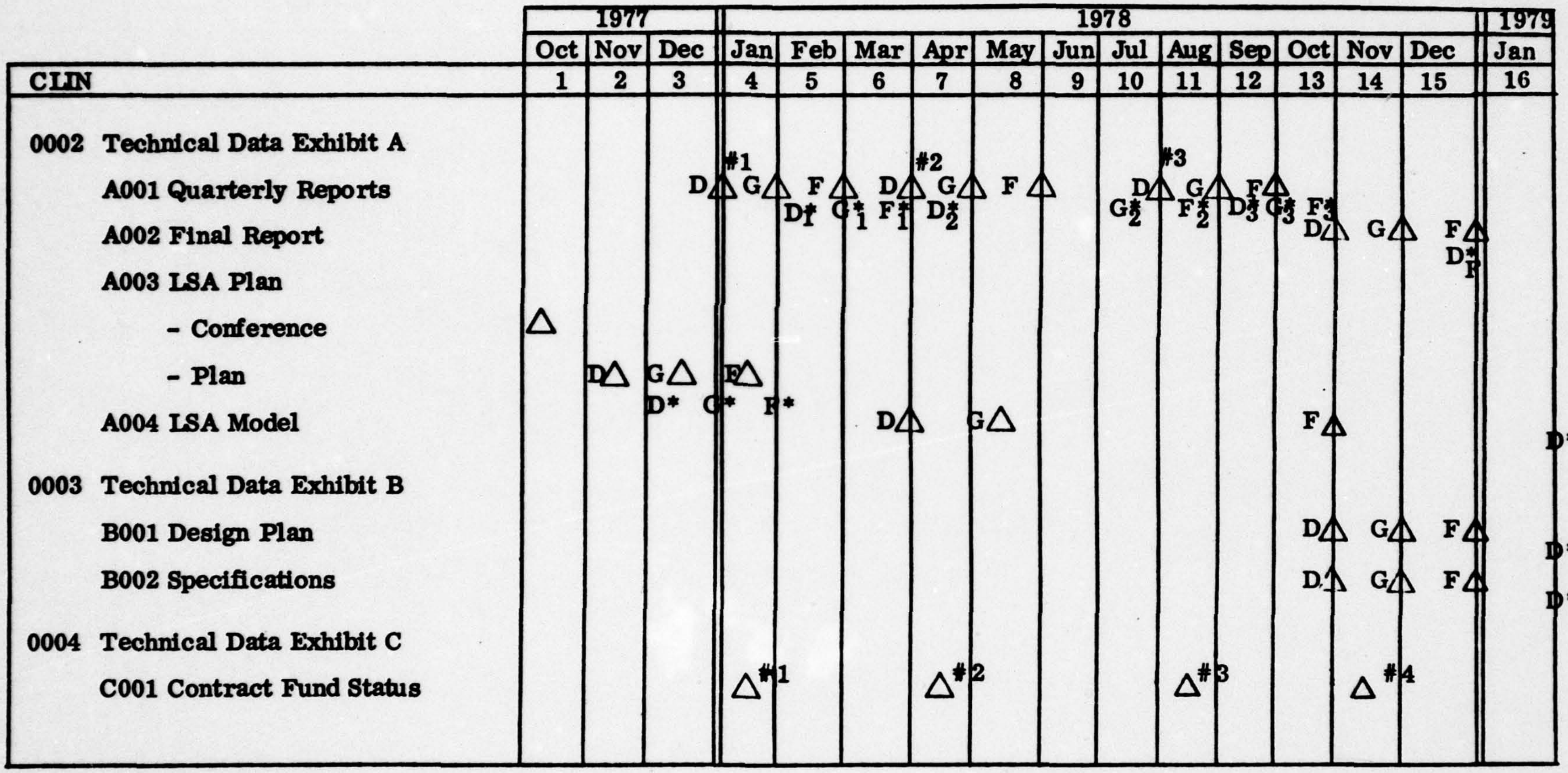
SECTION I

INTRODUCTION

This is the final report for the Vehicular Intercom System Study. Three quarterly reports preceded this report which presented progress covering the period of 30 September 1977 to 31 July 1978. In this report, Cincinnati Electronics presents conclusions on its study efforts. In addition, a system is described which meets the contract development specification, DS-AF-0246A(A), dated 14 February 1977.

SECTION II

CONTRACT DELIVERY SCHEDULE

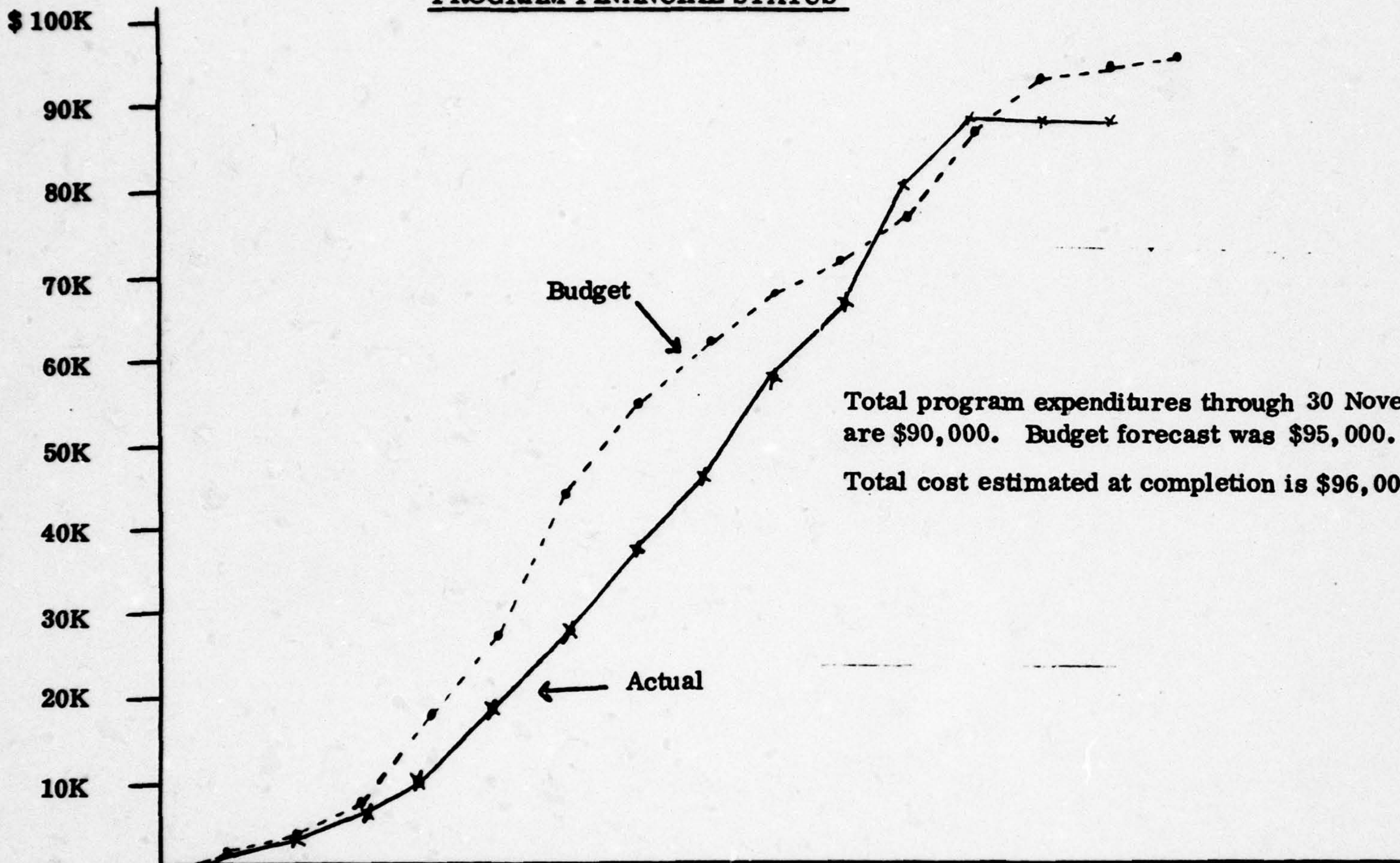


△ = Schedule * = Actual

NOTE: Schedule reflects approved 30-day extension of delivery items. The 30-day extension was requested in July 1978.

SECTION III

PROGRAM FINANCIAL STATUS



Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1.1	1.6	5.5	9.0	12.0	14.0	12.0	7.0	5.0	5.0	6.0	9.0	7.0	1.0	1.0	Budget $K
.9	1.4	5.0	3.9	7.9	8.7	8.9	9.1	11.9	9.7	12.3	7.5	.4	.3		Actual $K

Total program expenditures through 30 November 1978 are $90,000. Budget forecast was $95,000.

Total cost estimated at completion is $96,000.

SECTION IV

RESULTS OF STUDIES

A. GENERAL

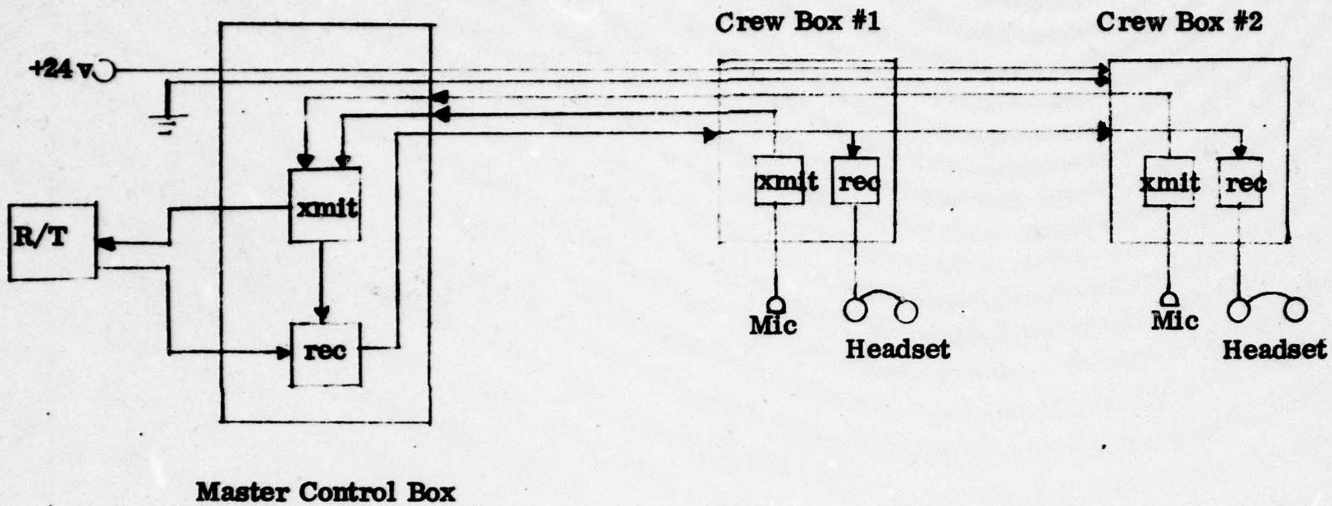
Two basic techniques have been considered for multiplexing information in order to reduce or eliminate the intercom system wiring. They are: Frequency Division Multiplexing (FDM) and Time Division Multiplexing (TDM). In general, the FDM system uses simpler electronics and requires a linear wideband transmission system, while the TDM system uses more complex electronics and can use a pulsed transmission system due to the digital nature of the data transmitted. In studying these two multiplexing systems, Cincinnati Electronics has decided that the TDM system is the most feasible in terms of ultimate size, reduction of cabling, system configurations, and life cycle cost. This conclusion is justified in the following paragraphs.

B. COMPARISON OF TDM AND FDM

1. Disadvantages of FDM

FDM is a linear, analog approach to multiplexing. Frequencies above audio are used as carriers and are frequency modulated. To receive a given audio signal, a crewmember would select a certain carrier and demodulate it for his audio. This process requires bandpass filters, audio filters, coupling capacitors, and, in short, a number of large discrete components. Thus, large-scale integration to reduce circuitry size would not be feasible since large capacitors would still be required external to the LSI chip. A rough look at circuitry size for the studied FDM system indicated the actual control box size would not be smaller than the present system.

In addition, the FDM system proposed by Cincinnati Electronics required as a minimum five conductors in the cable (two conductors for power and ground, two for audio and control for two crew boxes back-to-back, and one for monitor audio). See Figure 4-1. Note also that only two boxes could be connected in a back-to-back fashion. Thus, cables from the master control box may have to be run in parallel to connect additional crew boxes.



FDM CONDUCTOR REQUIREMENTS

FIGURE 4-1

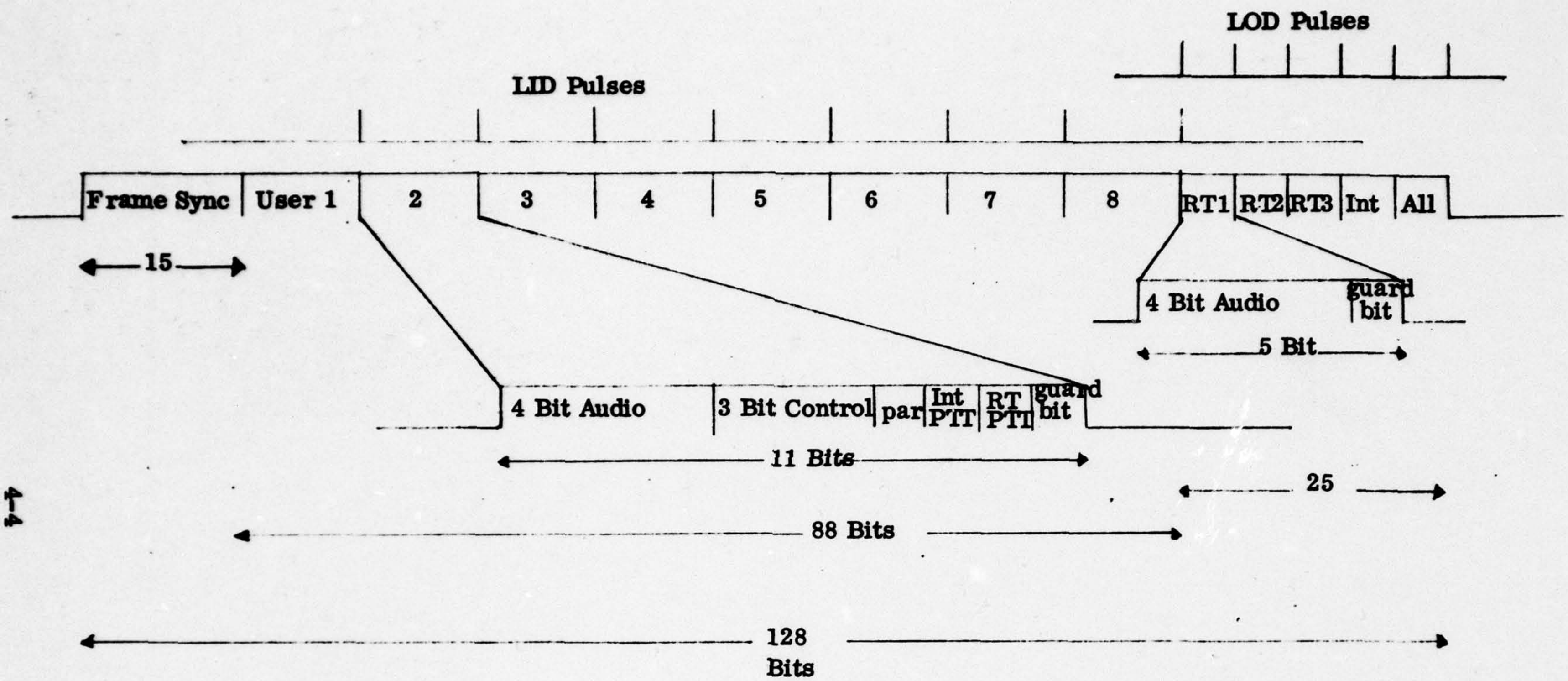
From a system life cost standpoint, the logistic cost of producing and stocking various lengths of special multiconductor cable and unique connectors such as is required for the existing system and would be required for the FDM system is, to say the least, expensive. The LSA model which will be submitted in January 1979 is expected to verify this conclusion.

Also, last but not least, Cincinnati Electronics was not able to find an inexpensive means for providing wireless audio accessories with the FDM approach. The most promising approach was the inductive radiator concept. We discovered in tests conducted in a M60 that transients produced by onboard motors and other equipment caused interference unless the transmitter power was increased to override the interference. However, with increased transmitter power, crewmembers would interfere with each other and the ability for one crewmember to be uniquely tied to his wall-mounted control box was lost. Providing separate channels for each user required eight different control boxes, or a very complex switching arrangement to retune the antenna, VCO transmitter and PLL receiver. For a fuller discussion of inductive radiators, see the Third Quarterly Report, Section IV, C. 2. a.

2. Advantages of TDM

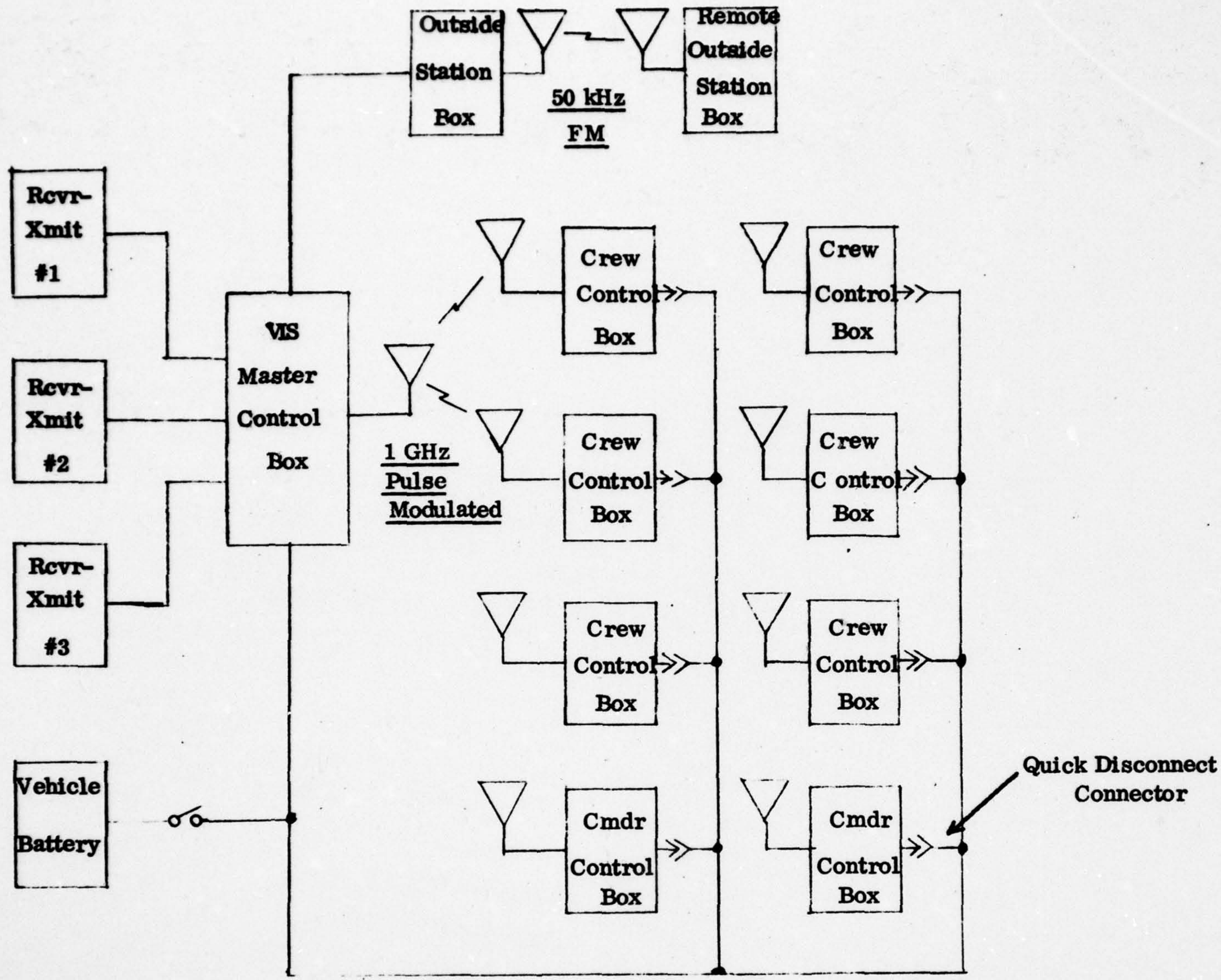
Time division multiplexing places all information into a digital stream separated from each other by time of occurrence. For example, a crewmember places his audio in a time slot to send it to the master control box. The master control box extracts the audio and places it in the intercom time slot which is then transmitted to every crew box (see Figure 4-2). Since information is placed into a digital format, wireless transmission of this information becomes relatively simple by pulse modulation. To accommodate the eight crewmember and three receiver-transmitter requirements, bit rates for the TDM system approach one megabit (see Figure 4-14). Therefore, bandwidth requirements forced Cincinnati Electronics to select a high frequency carrier to pulse modulate. In previous reports, Cincinnati Electronics investigated infrared and microwave frequency bands. Microwave was chosen since it is not blocked by nonmetallic objects, such as crewmembers, as easily as is infrared.

Microwave used outside the vehicle hull was not feasible due to unpredicable distance of transmission causing TEMPEST compromise. The inductive radiator approach was chosen for a wireless, remote outside station. The recommended VIS, TDM system is shown in Figure 4-[illegible].



TDM FRAME STRUCTURE

FIGURE 4-2



BLOCK DIAGRAM, VIS SYSTEM

FIGURE 4-3

The advantage of this system over the FDM is as follows. The only cabling required to inside crew boxes is cabling for power. No special conditioning of vehicle power is required; and, therefore, it can be acquired from any nearby source. A small battery will be built in the crew box; and, since the crew box can be mounted on the crewmember, totally wireless operation will be possible for short periods of time. The battery will recharge from vehicle power when the crew box is connected.

TDM uses large amounts of logic gates for control purposes. However, logic gates are not difficult to integrate into LSI chips for reduction of circuitry size. Unlike the FDM system, large discrete components are not required. Thus, Cincinnati Electronics expects to be able to reduce the physical size of the TDM control boxes such that they can be easily mounted on the crewmember.

Although LSI is expensive to implement during development, LSI chips are less expensive than their discrete dual-in-line circuit in high volume manufacturing. Considerable savings should occur over the life of the VIS system.

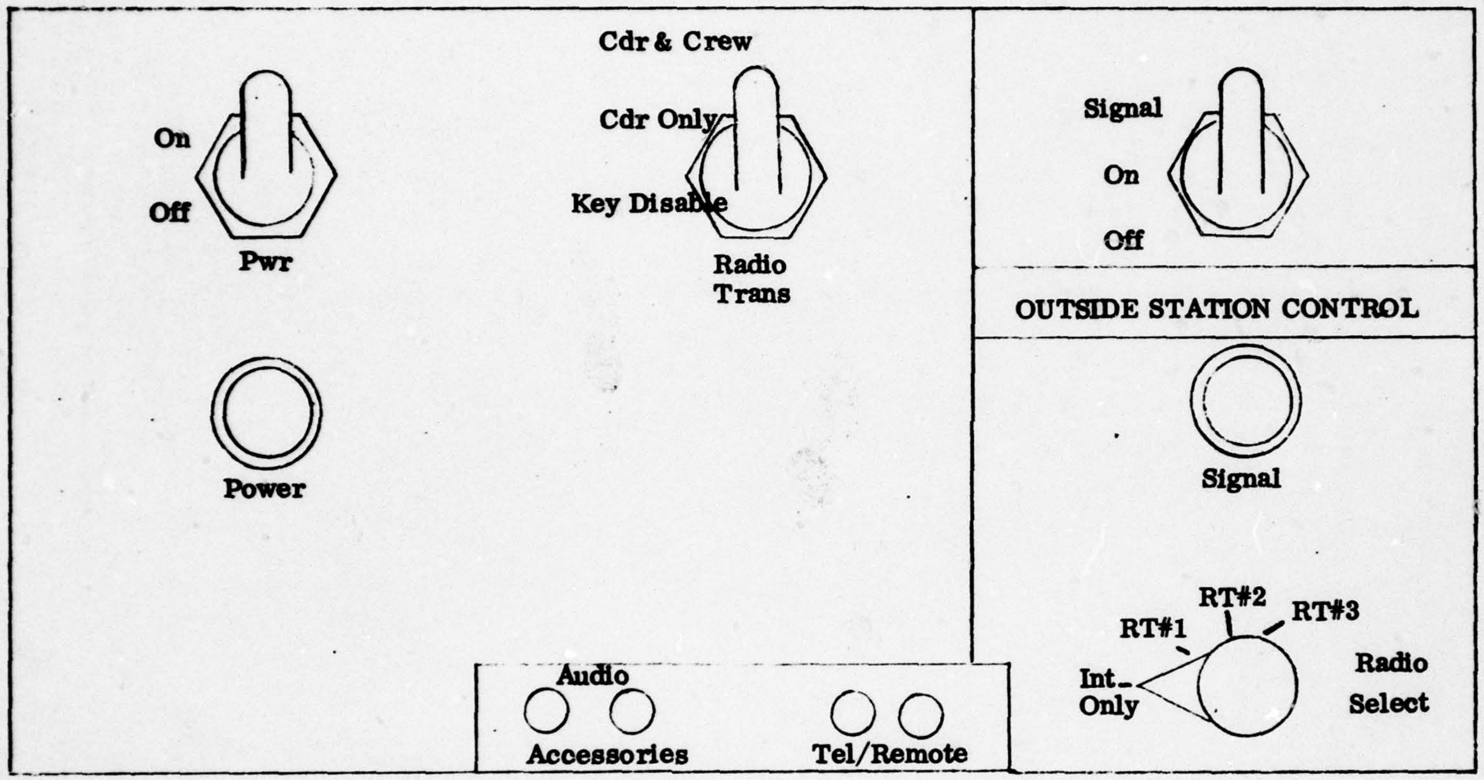
3. The Recommended TDM System

The recommended TDM system will be composed of a master control box, a crew control box, a commander control box, an outside station box, and a remote outside station box. A block diagram of this system was shown in Figure 4-3. Each of these system components will be discussed in this section.

a. Master Control Box

The master control box interfaces between the onboard receiver-transmitters and provides control of the TDM operation. Clocks are generated in this box and Manchester encoded with data. Crew boxes extract the data and clock via a pulse modulated, microwave link. The master control box is expected to be mounted near the vehicular commanders position. Located on the box's front panel are switches which control power to the box, PTT to the onboard receiver-transmitters, and control of the outside station. Also, terminal posts are located on this front panel for telephone and audio wires. A possible front panel layout is shown in Figure 4-4.

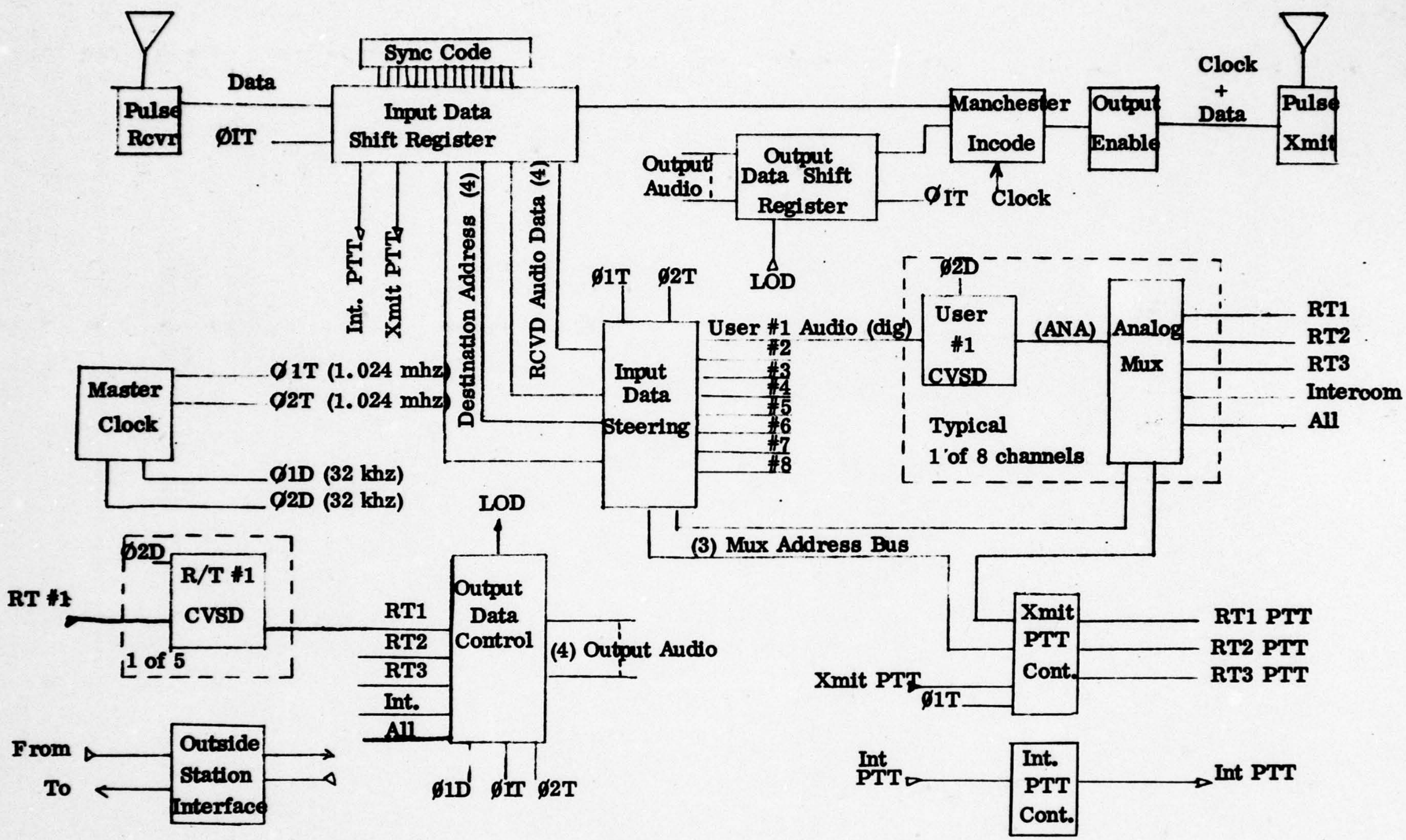
1) Master Control Box Block Diagram - A block diagram of the master control box is shown in Figure 4-5. The function of each of these blocks will be briefly described here.



VIS MASTER CONTROL BOX

FRONT PANEL

FIGURE 4-4



MASTER CONTROL BOX

BLOCK DIAGRAM

FIGURE 4-5

(a) Master Clock - This circuit generates all high speed (1 MHz) data clocks as well as the low speed (32 kHz) clocks for audio processing in the CVSD's.

(b) Synchronization and Input Data - A fifteen-bit sync pattern is generated and inserted onto the data stream at the beginning of each frame. This same circuit also provides user data in parallel form.

(c) Output Enable Control - During those periods of time when the Controller is not putting data on the data line, this circuit causes a high impedance to be presented to the data line to prevent distortion of user data.

(d) Input Data Control and Steering - The controls necessary to load and steer data from each of the eight users to their proper destination are generated in this section.

(e) Output Data Control and Steering - Loading and steering control circuitry in this section insures that the proper audio is loaded into each of the last five time slots in the frame. The output data shift register receives output audio data in parallel block form and inserts it into the data stream in serial form at the proper time.

(f) Transmit PTT - Each user's transmit PTT bit is steered by this circuit to the selected RT.

(g) Intercom PTT - This circuit recognizes a PTT from only one of the eight users to provide a lockout function for the remaining PTT lines.

(h) Outside Station Interface - This circuit decodes outside station lines and routes audio to intercom or proper receiver-transmitter. It also generates a signal tone which is injected into the intercom audio to alert the commander of an outside station call.

(i) Pulse Receiver and Transmitter - Microwave Frequency Receiver and Transmitter - In transmit, a microwave oscillator is gated on and off. In receive, a simple detection circuit detects pulsed microwave and squares the resulting signal for logic processing. Bandwidth of receiver and transmitter is determined primarily by "Q" of the antenna.

(j) Manchester Encoder - A means of combining clock and data for transmission as a serial bit stream.

b. Commander and Crew Control Boxes

The commander and crew control boxes are identical in operation. The commander box has one more volume control than the crew box. This control allows the commander the ability to adjust his intercom level relative to his radio level. At a crew box, these levels are preset with intercom three decibels (3 dB) higher than the radio.

The crew/command control boxes allow the user to select what audio he desires to monitor and which radio he desires to transmit on. His box has a volume adjustment and a button to check the condition of his internal battery. Possible front panel configurations for crew and command boxes are shown in Figures 4-6 and 4-7. Eight unique time slots (channels) are provided. A screwdriver adjustable switch allows selection of these time slots. Once selected such that all crewmembers have an unique channel, no further adjustment of this switch is needed.

The internal battery will provide for totally wireless operation for periods up to two (2) hours at temperatures above -20°C. This limitation is required to keep the battery size and, thus, the control box size to a minimum.

1) Crew/Commander Control Box Block Diagram - Figure 4-8 is a block diagram of the Crew/Commander Control Box. Each of the sections will be briefly described here on a functional level. A more detailed discussion of the box can be found in the Third Quarterly Report, Section IV, 2.f.

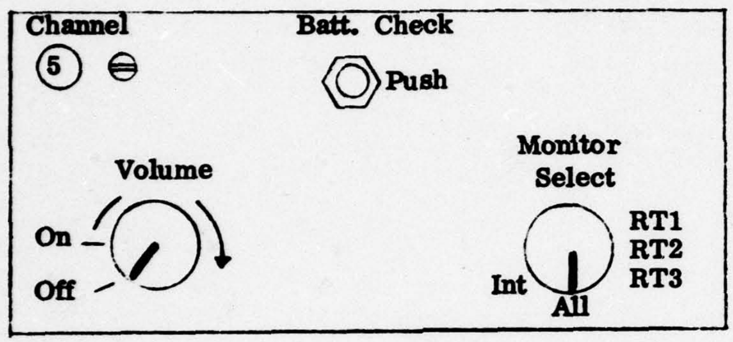
(a) Clock - The clock is received from the Controller and passed to the user circuitry. A low speed clock is also derived from Ø2T.

(b) Data Shift Register - The serial data stream is directed through this register to be converted to parallel form. Transmit data is also loaded into this section.

(c) Sync Recognition and Recovery - The serial data stream is examined in this section for the sync pattern in order to establish synchronization between the user and the Controller. This circuit also will detect missed sync patterns and provide for synchronization recovery.

(d) Output Data and Loading - The ten bits of user generated data come from this section. Four bits of digitized audio, a three-bit destination address plus parity, transmit and intercom PTT. This circuit also generates the controls necessary to load the data into the serial data stream at the proper time.

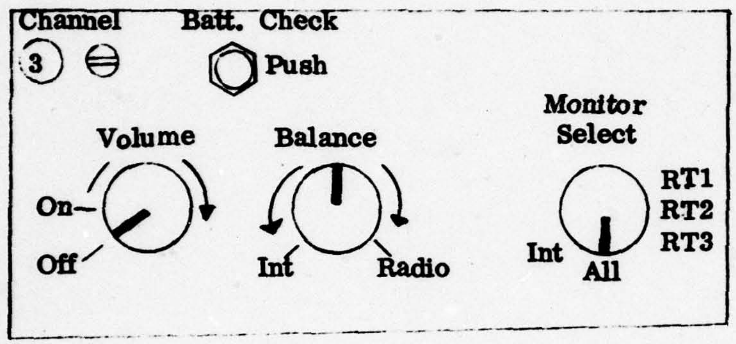
(e) Output Enable Control - The output control allows the data from the user to be put on the serial data stream only at the proper time. This is to prevent possible data distortion in the event of missed sync.



VIS CREW CONTROL BOX

FRONT PANEL

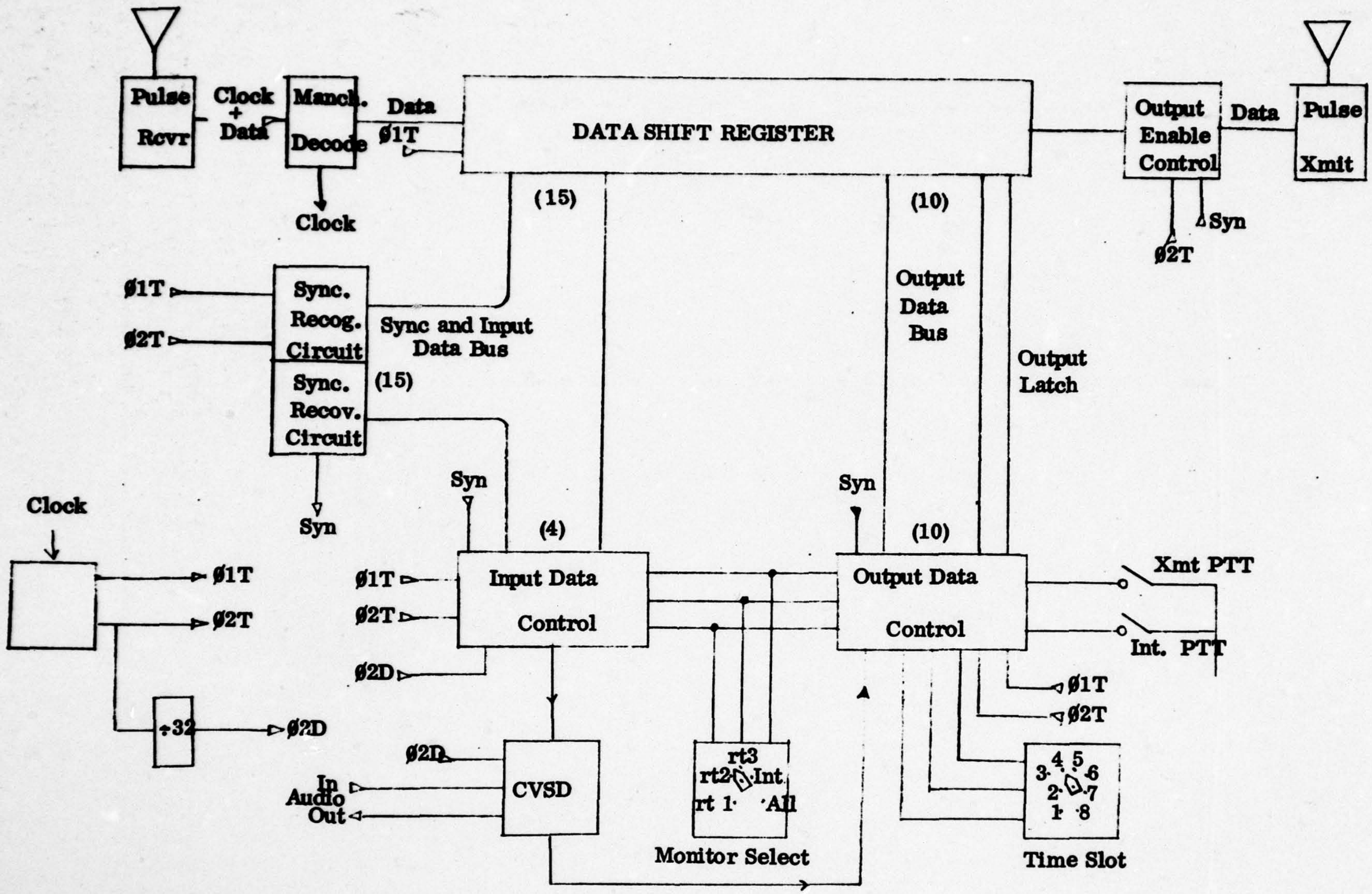
FIGURE 4-6



VIS COMMANDER CONTROL BOX

FRONT PANEL

FIGURE 4-7



CREW/COMMANDER CONTROL BOX

BLOCK DIAGRAM

FIGURE 4-8

(f) Input Data Selection and Loading - The operator can select one of five audio sources with the audio select switch. The information from this switch is used to select the proper time slot within the frame and load it into a shift register to be sent to the CVSD for decoding.

(g) CVSD - The CVSD selectively encodes analog audio or decodes digital audio depending on the state of PTT.

(h) Pulse Transmit/Receive and Manchester Decode - These circuits function in like manner as in the Master Control box.

c. Outside Station/Remote Outside Station Box

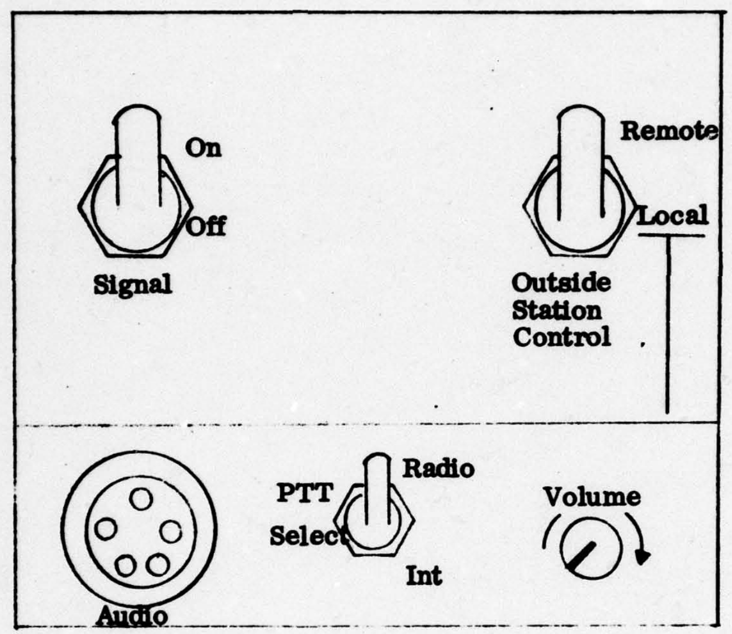
The outside station box provides direct wired input into the intercom system by way of a standard H-250 handset. It also provides transmit and receive capabilities to and from the remote outside station box. The remote outside station box receives power for battery charging from the outside station box and can communicate via low frequency, near field radiation with the outside station box at a distance of fifteen (15) meters minimum. Possible front panel controls are shown in Figure 4-9 and 4-10. Both outside boxes would be housed in the existing protective box located on the tank hull.

1) Block Diagram of Outside Station System (Figure 4-11) - A brief discussion of each functional block is presented below. A more detailed discussion of the receiver-transmitter can be found in the Third Quarterly Report, Section IV, C.2. In that report, Cincinnati Electronics was still considering its use to achieve wireless headsets for inside crew-members. As an outside station, a different antenna would be required as mentioned in Section IV, C.1, of the Third Quarterly Report.

(a) Outside Station Box

- Pre-amp and Control - This circuit amplifies microphone audio and places a DC voltage on the line with the audio. The master control box detects this voltage level to determine proper routing of the outside station audio, for signal, and PTT action.

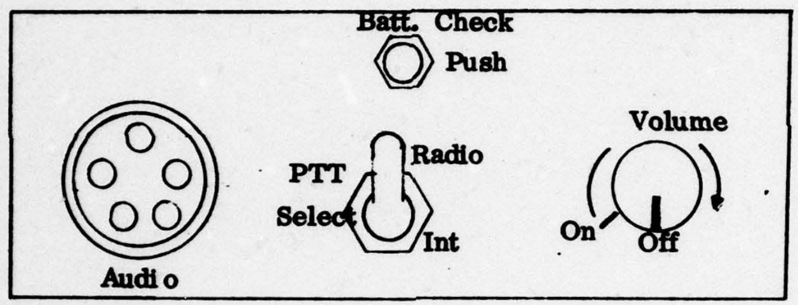
- Headphone Amp - This circuit drives the H-250 handset headphone when connected f local operation.



VIS OUTSIDE STATION BOX

FRONT PANEL

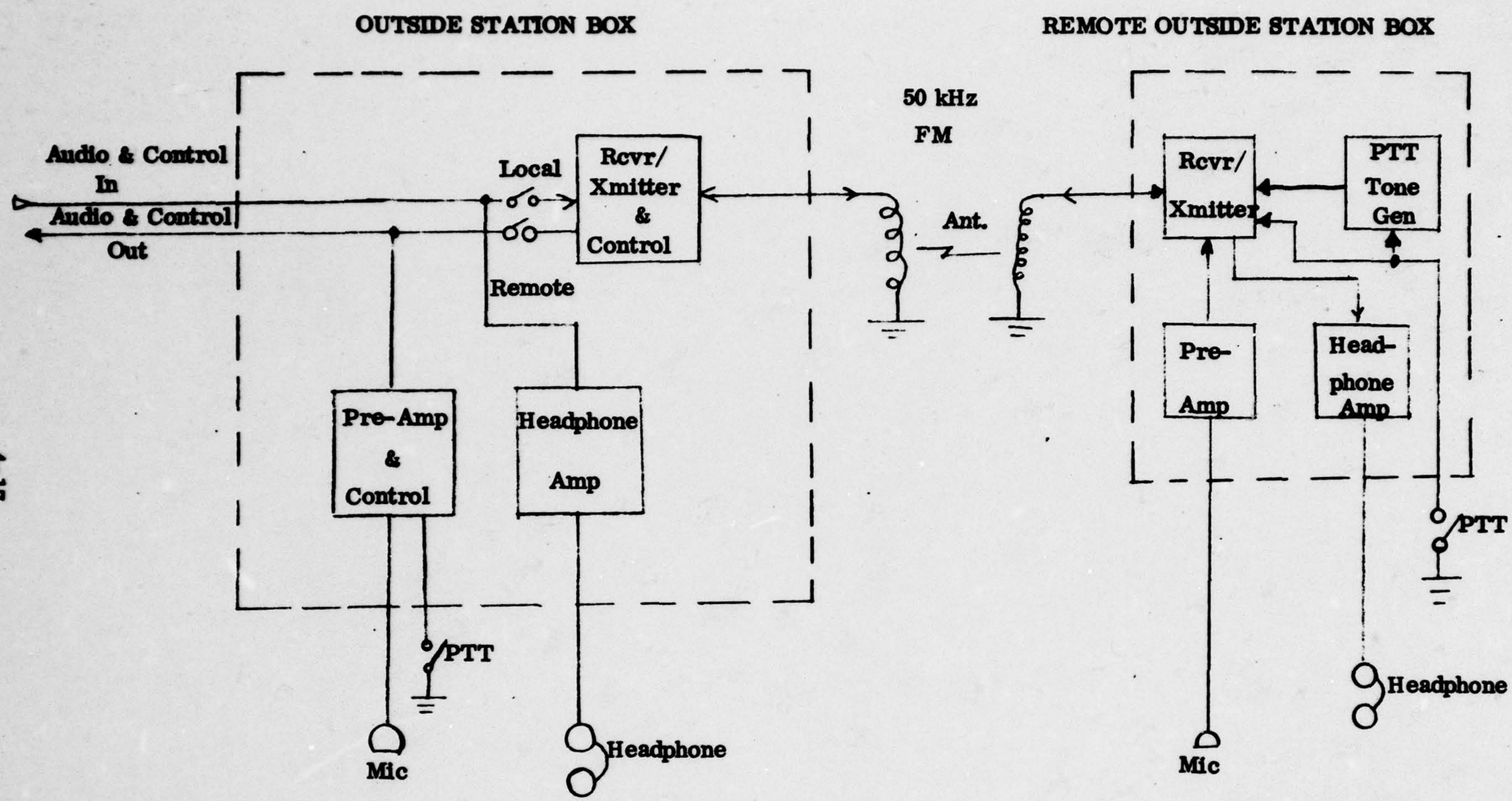
FIGURE 4-9



REMOTE OUTSIDE STATION BOX

FRONT PANEL

FIGURE 4-10



OUTSIDE STATION SYSTEM BLOCK DIAGRAM

FIGURE 4-11

- Receiver-Transmitter and Control - A 50 kHz, FM receiver-transmitter with a tone detector. Tones are sent from the remote station as a means of transmitting PTT information. DC levels are sent by the master control box with audio to key the transmitter or for signaling purposes.

- Antenna - Optimum antenna design will have to be coordinated with available mounting space on existing and future vehicles. A horizontal loop antenna is preferred.

(b) Remote Outside Station Box

- Receiver-Transmitter - A 50 kHz, FM receiver-transmitter.

- Pre-Amp - Amplifies microphone audio to drive transmitter.

- Headphone Amp - Amplifies received audio to drive H-250 handset.

- PTT Tone Generator - Generates two subaudio tones. One indicates a radio PTT is desired and one indicates intercom is desired. These tones are detected by the receiver-transmitter in the outside station box.

C. CONCLUSIONS AND RECOMMENDATIONS

1. Bit Rate Versus Audio Bandwidth

From conduction of listening tests using a 32 kilobit CVSD, a 3 kHz low pass filter produced audio which sounded very good. Electrical tests conducted show a significant increase in high frequency distortion when Cincinnati Electronics went from a 3 kHz to a 6 kHz low pass filter (see Figure 4-12 and 4-13). Therefore, having a 6 kHz audio bandwidth is not optimum for a 32 kilobit CVSD. Using a higher bit rate CVSD would cause an increase in VIS system, TDM bit rate, and problems with control, synchronization, antenna bandwidth, and so on (see Figure 4-14). Therefore, Cincinnati Electronics recommends dropping the 6 kHz audio bandwidth requirement in favor of a 3 or 4 kHz bandwidth.

2. Outside Station Requirements

The single driving factor which caused the use of an unique wireless system for the outside station was TEMPEST considerations. The resulting recommended outside station will meet TEMPEST limits but at the expense of increased system cost.

There is some possibility that when remote outside stations are used in close proximity, to other vehicles with remote stations in use, that interference could occur. However, the phase lock loop receiver will receive only the stronger signal (FM capture) which was assumed to be that user's vehicle.

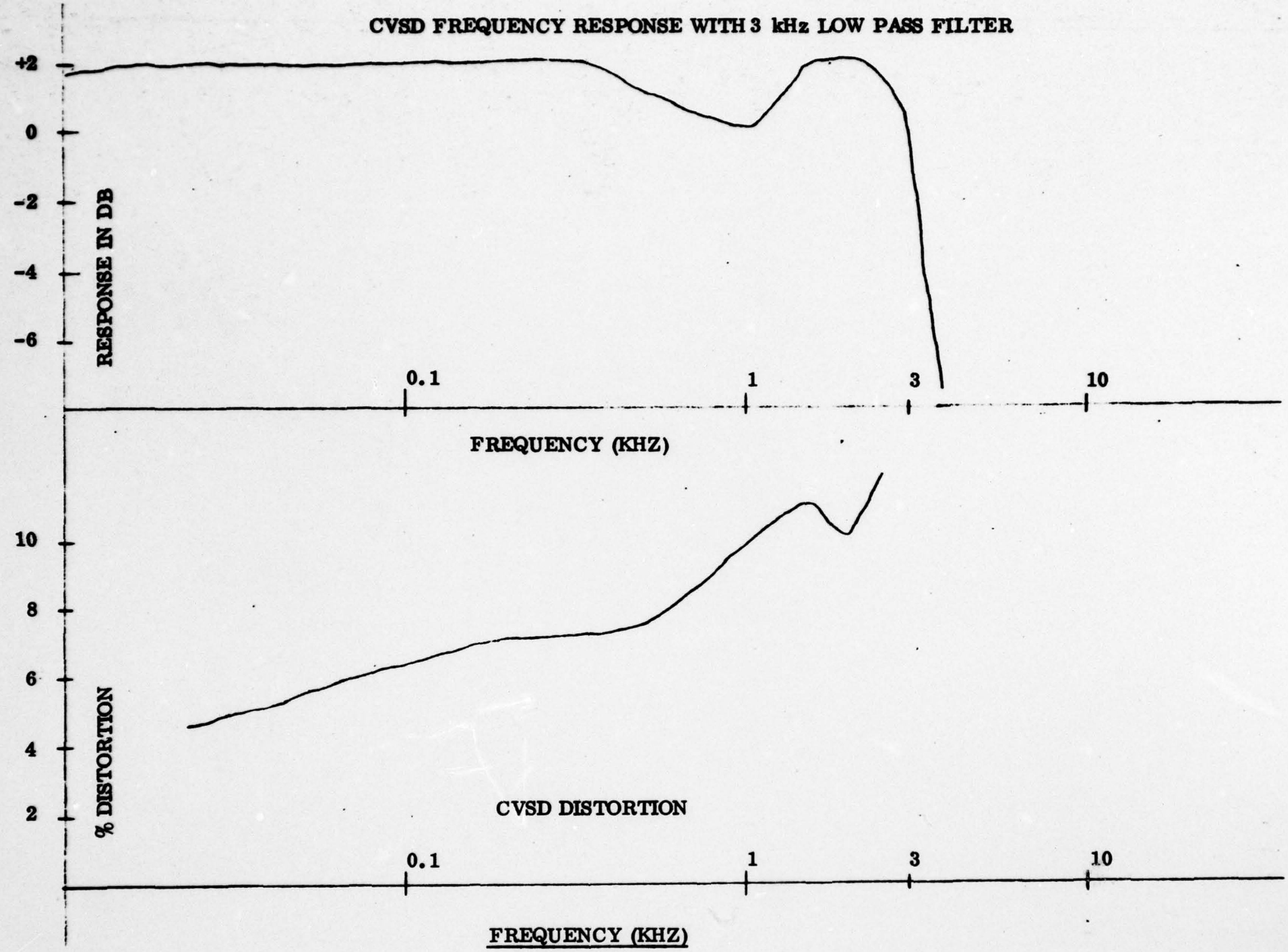
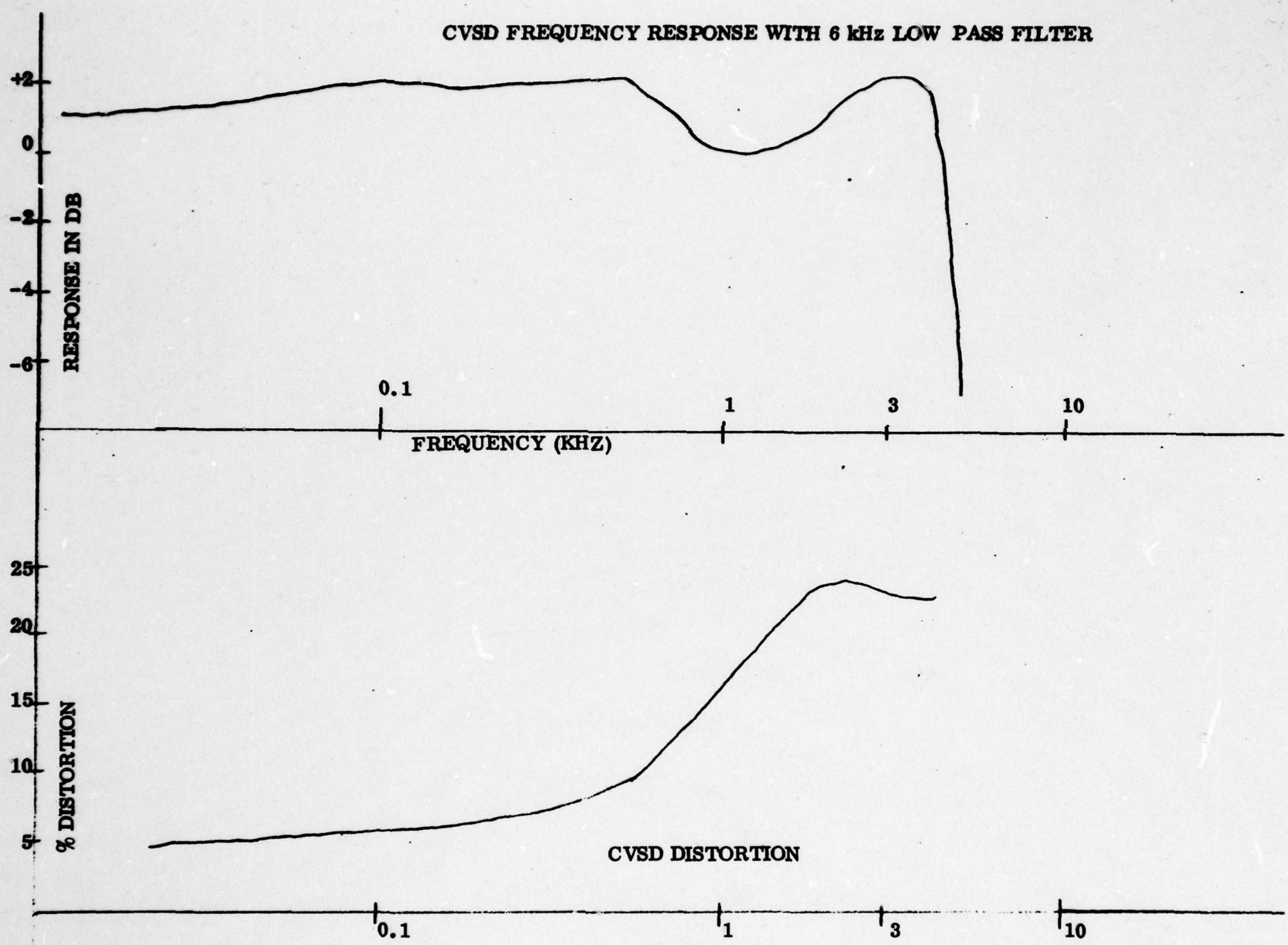

CVSD FREQUENCY RESPONSE WITH 3 kHz LOW PASS FILTER
+2
0
-2
-4
-6
RESPONSE IN DB
0.1
1
3
10
FREQUENCY (KHZ)
10
8
6
4
2
% DISTORTION
CVSD DISTORTION
0.1
1
3
10
FREQUENCY (KHZ)

FIGURE 4-12



FREQUENCY (KHZ)

FIGURE 4-13

From Figure 4-2, the frame is composed of 128 bits. This frame has to be circulated in the time it takes for the crew control box CVSD to generate four (4) bits of transmit audio or to receive four (4) bits of receive audio. Therefore, the total TDM system bit rate is as follows:

1. 32 kilobit CVSD

$$\frac{32,000}{4} \times 128 = 1,024,000 \text{ bits/second}$$

2. 64 kilobit CVSD

$$\frac{64,000}{4} \times 128 = 2,048,000 \text{ bits/second}$$

Figure 4-14. TDM System Bit Rate Calculation

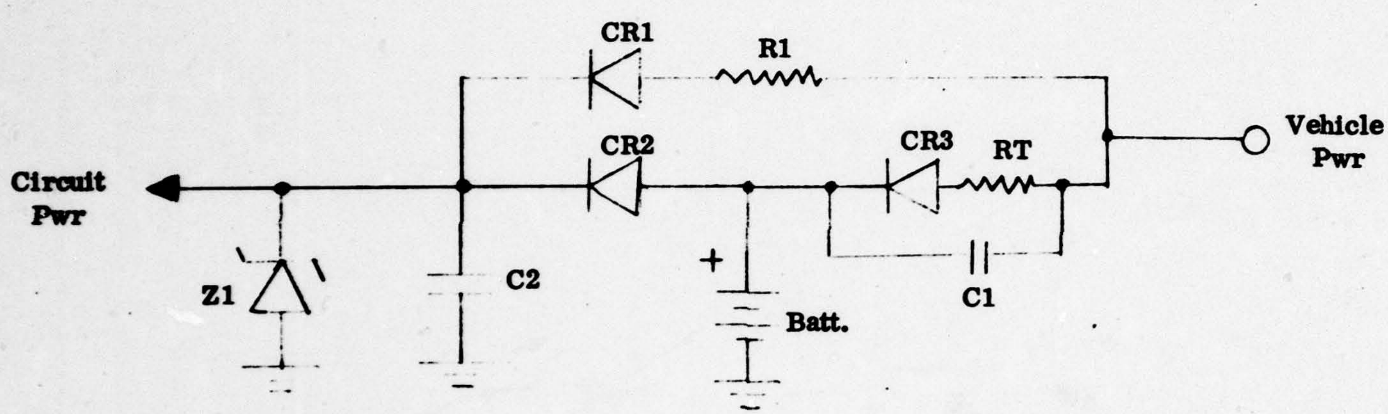
3. Microwave Pulsed Receiver-Transmitters

Working models were built, operating at a 32 kilobit rate. These models were taken to Fort Knox and tested under COTR supervision in an APC and M60 tank. Transmitting pulsed information via reflections in the vehicle crew compartment worked fine for members in the turret of the tank and troop area of the APC. However, in both vehicles, the driver areas are separate and far forward; and, from the driver positions, Cincinnati Electronics personnel experienced difficulty receiving transmissions from the turret or troop area. It is felt at this time that the crude, quickly built models were to blame for this lack of communication. However, some testing to determine transmitter signal strength and receiver sensitivity will be required before these parameters can be specified for a production unit.

4. Battery Considerations

The recommended use of a rechargeable battery in the crew control boxes for part time, totally wireless operation is a compromise between battery logistic problems and the development specification. If a system was totally dependent on batteries for its operation such as is the PRC-77 radio, spare batteries would have to be supplied within the vehicle and at direct support maintenance. Batteries have a self-life; and, therefore, a continuous supply of batteries would be required for system operation. On the other hand, if the system was designed such that a battery failure did not cause a system failure such as is recommended, the logistic problem is highly simplified. Battery failure would cause a decrease in system flexibility; i.e., the concept of total freedom of movement, but not loss of system operation. Hence, spare batteries would not be required except in vehicles where this flexibility was a necessity.

A circuit arrangement which allows either battery operation or wired power operation is shown in Figure 4-15. Zener Z1 provides overvoltage protection. Resistor R_T is a temperature sensitive, variable resistor which limits charge current at low temperatures. Capacitor C_1 allows short rise time transients to be coupled to the battery and thus shorted to ground. Capacitor C_2 provides additional transient protection. Diodes CR1, CR2, and CR3 allow power to the circuit and for battery charging, but prevent battery discharge when vehicle power is off. For an additional discussion of batteries, see Third Quarterly Report, Section IV, D. Note how much simpler this charge circuit is compared to the one described in the Third Quarterly Report, Section IV, D. 5.



BATTERY/VEHICLE POWER OPERATION

FIGURE 4-15

SECTION V

LSA MODEL

The final Logistic Support Analysis will be conducted on the recommended TDM semi-wired approach. This analysis is expected to show that the latest TDM approach is more cost effective than the wired FDM. In the Third Quarterly Report, Section V, the wired FDM approach was shown to be more cost effective than a wired TDM approach. A significant portion of the cost of both systems was cabling.

SECTION VI

AVERAGE COST ESTIMATE

The average cost estimate will be included with the LSA Model. A breakdown of system costs and trade offs between parts costs and reliability requirements can be clearly shown in the LSA report.

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ADDENDUM

Paragraph 3.b., page 4-10, after the sentence, "Once selected that all crew-members have a unique channel, no further adjustment of this switch is needed." The following paragraph should be added:

Time slot number one is reserved for the vehicle commander. Only commander boxes may access this channel. This feature allows for vehicle commander override of crew radio actions and provides for additional system capabilities if desired. More than one commander box may be used in a system; however, two commander boxes cannot select channel one simultaneously.

Paragraph 3.d. below is added after Paragraph 3.c., page 4-18:

d. Radio Remote Control

As with the existing VIC-1 system, radio remote control will be accomplished with a wall mounted box. A box is expected to be developed as part of the SINCGARS radio program for remote control of the radio. The circuitry may have to be repackaged to provide mounting in the existing mounting holes for a C 2298 or C 2297 control box.